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Department of Ecology

Management of the broad bean weevil (*Bruchus rufimanus* Boh.) in faba bean (*Vicia faba* L.)

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B. Luka, INRA (Infested faba beans)
Australian Department of Food and Agriculture (*V. faba* in bloom)

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Summary

Bruchus rufimanus Boh. is a common pest on faba beans (*Vicia faba* L.) all over Europe and worldwide. The area of faba bean production is increasing in Sweden and in Europe, partly encouraged by the CAP subsidies for legume crops and diversified crop rotations. At the same time, number of the insecticides commonly used against *B. rufimanus* have been removed from the market as pollinators risk to be harmed as the treatment timing corresponds to crop flowering. In Sweden, only one insecticide is available and its efficacy against *B. rufimanus* is not well established. The pest pressure is likely to increase if no measures are taken to reduce the population. This has increased the interest in alternative management methods in Europe, particularly so in the UK and in France where faba beans is extensively grown.

This report presents an overview of *B. rufimanus* biology and management strategies. This report is the result of a literature search including scientific literature and other available documentations (e.g., grower organizations, technical institutes). Additionally, contacts with technicians, referring advisors and researchers across Europe involved in research projects related to *B. rufimanus* management, enabled me to obtain an up-to-date overview of the advancement of their projects that I present in this report.

In conclusion I suggest further investigations that would clarify the risks for faba bean production and help identify measures both in term of field management and direct control that could be recommended in Sweden.

Introduction

Faba bean production in Sweden

Faba bean (*Vicia faba* L.) production has increased in the past years in Sweden (Fig. 1). The increase agricultural area cropped with faba beans is a response to replace contested importations of soybeans for animal feed and is encouraged by EU subsidies for diversified crop rotations. Only spring varieties are grown in Sweden as winter varieties are susceptible to spring frost.

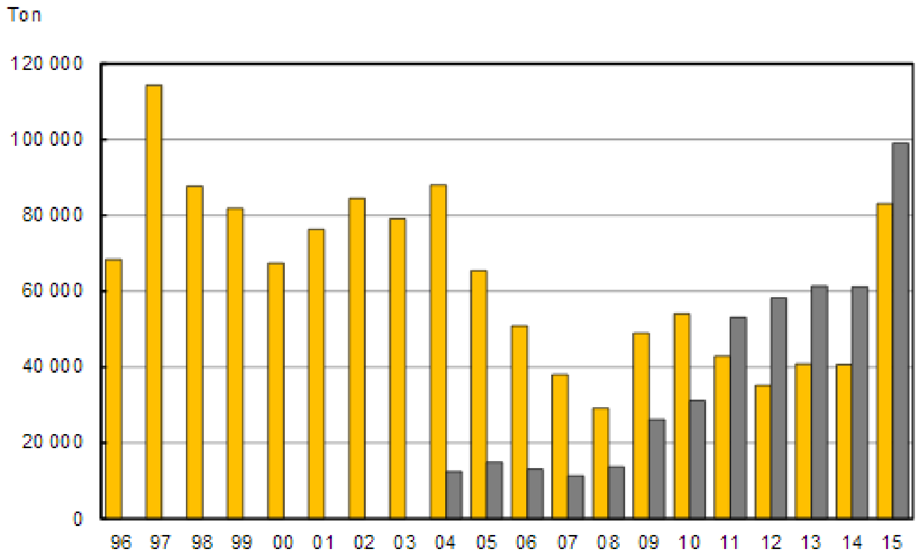

Figure 1. Peas (yellow) and faba bean (grey) production in Sweden 1996-2015 (Total production, in tons at 15% moisture content). From: Jordbruksverket (2016a).

Two seed production companies are currently supplying faba bean seeds in Sweden: Scandinavian seeds and Lantmännen. Both produce their seed in Sweden. Cultivars grown in Sweden are Gloria, SW Taifun, Julia, Alexia, Marcel, Vertigo, SW Fuego and: Alexia eko, Julia eko, Banquise eko, SW Fuego eko in Organic production (Scandinavian Seed AB, 2015). Sowing is done early in spring (April-May) and the crop reaches full maturity as far as October according to climatic conditions. Early maturing varieties are demanded because of the short growing season in Sweden (Wallenhammar et al., 2013).

In 2015, faba beans were grown in most regions in Southern Sweden up to Uppland. Regions that grow faba beans are, by order of importance in hectare and with regions where more than 1000 ha are grown in bold: **Västra Götaland, Östergötland, Skåne, Halland, Västmanland, Södermanland,** Värmland, Örebro, Uppsala, Kalmar, Gotland, Blekinge and Stockholm, Jönköping and Kronoberg (Jordbruksverket, 2016a).

Pest pressure in Sweden and Northern Europe

Bruchus rufimanus is present in most faba bean growing regions in the world and is ‘established’ all over Europe, including Scandinavia (Hulme, 2009). It is found in southern Sweden (particularly Skåne, Västergötland, Östergötland, and Uppland). In Finland, there has been no record of *B. rufimanus* since 1960

(Rassi et al., 2015), but as the cropping area of broad bean has increased during last ten years (in 2015: about 17 000 ha) it may presumably be present in the field but has not yet been recorded (Erja Huusela-veistola, personal communication, June 2016). Similarly, the cropping area of broad bean is expected to increase in Denmark (Heilesen, 2016). *Bruchus rufimanus* is currently mentioned in the Danish red list as 'regionally extinct' (Wind and Pihl, 2004) although it has been recorded in storage (Hagstrum, 2013, p. 149).

Bruchus rufimanus was first identified in Sweden in 2008 (Gunnel Andersson, personal communication to Lina Norrlund). The pest had then been present in Southern Sweden for a few years without causing serious damages. Since then, pressure and damages from *B. rufimanus* in Sweden vary from year to year, with a particular severe attack observed in 2009 (up to 100% damage) and in 2010 (up to 55% damage) and a small pressure observed in 2011 (5% damage) (Berg and Wikström, 2011). *Bruchus rufinamus* was first recorded in Uppland in 2015, suggesting the pest is moving north (Lina Norrlund, personal communication, Mar. 2016).

Besides *B. rufimanus*, the black bean aphid (*Aphid fabae* S.) and the pea leaf weevil (*Sitona lineatus* L.) and diseases are other important pests of field beans in Sweden. Particularly, the soil born Chocolate spot disease *Botrytis fabae* S., and the root rot disease *Phytopthora pisi* (H.), are common in Sweden. Long term rotations (6 to 8 years) are advised to prevent disease outbreaks (Jordbruksverket, 2014), particularly in organic production where no fungicide is used (Jordbruksverket, 2015).

Biology of the broad bean weevil

The broad bean weevil, *B. rufimanus* is univoltine (one generation per year) (Fig. 2). It reproduces in spring in faba bean crops, lays eggs on the young pods, develops in the growing seeds and overwinters as adults in shelters, or as larva or pupa diapause in the stored seeds (Fig. 3). Adults are 3 to 5 mm in length.

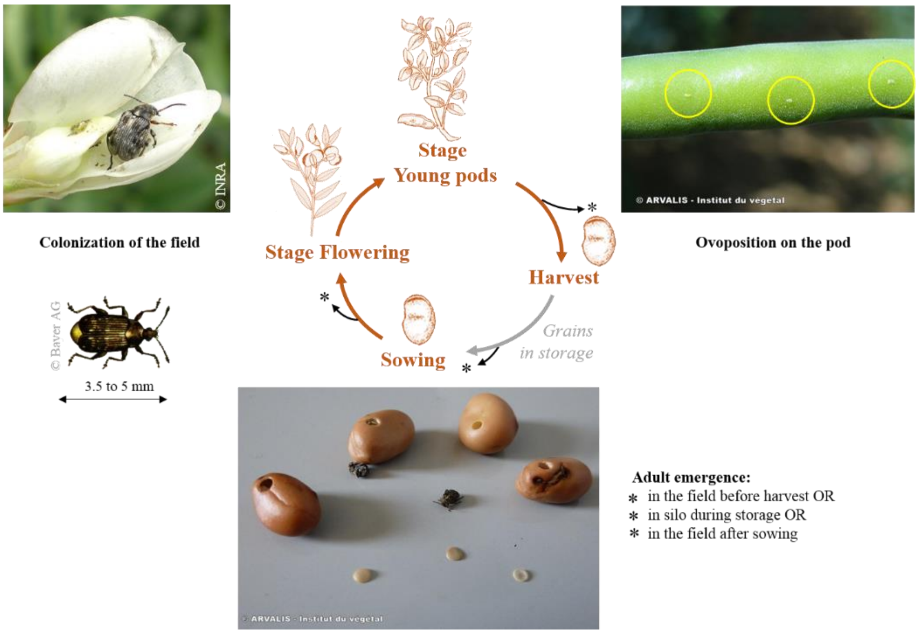

Figure 2 Bruchus rufimanus *cycle during faba bean cropping season. ER. Pictures: INRA, Arvalis institut du vegetal.*

Life cycle

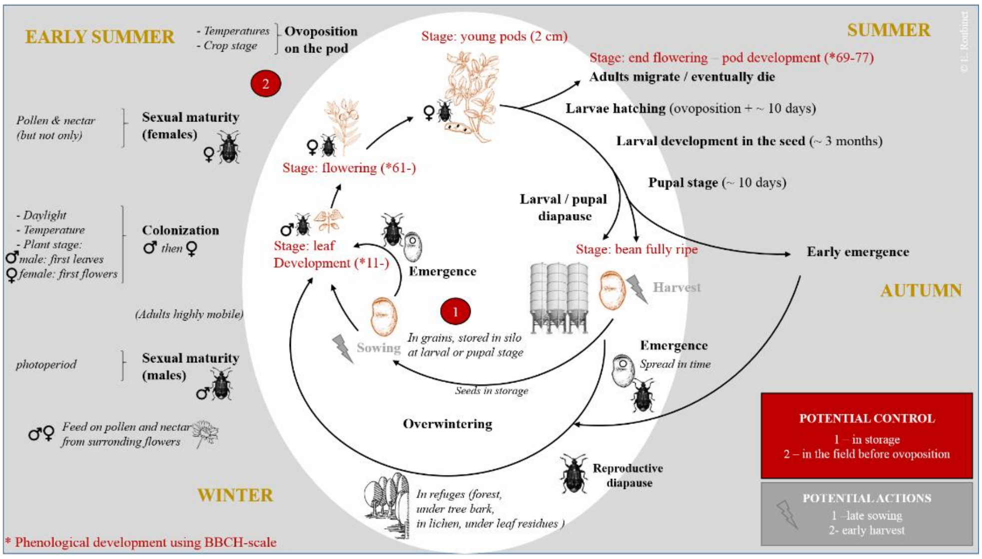

Figure 3 Life cycle of Bruchus rufimanus*, the broad bean weevil on faba bean, its potential control measures and actions in field management. ER.*

Overwintering

Adults are in reproductive diapause and overwinter in protected sites such as under tree barks, particularly of old, standing trees (Becky Ward, personal communication, April 2016), hedgerows, lichen, and in forests (Leppik et al., 2014; Tran and Huignard, 1992) or leaf litter (Bruce et al., 2011). According to B. Ward (personal communication, April 2016), survival rates of overwintering adults in the UK decrease when winter temperatures are mild, which could increase the potential for *B. rufimanus* to establish in Sweden where winters are usually dryer and colder than in the UK. *Bruchus rufimanus* is particularly resistant to cold winter due to its flexible overwintering strategies in protected sites, so that establishment in Sweden, even in higher latitudes is likely. However, no data on its ability to overwinter in natural habitats in Sweden has been found. Insects become active and leave their hibernation sites when temperature reach 15°C (in France, ARVALIS, 2016). They can be observed feeding on pollen and nectar of nearby flowers and particularly on Fabacae and *Vicia* spp. (Hoffmann, 1945, p. 43, Brigitte Frerot and Blandine Raffiot, personal communication, June 2016), although more recent sources consider them as monophagous, only found in faba beans (Leppik et al., 2014).

Some *B. rufimanus* survive during winter in larval or pupal diapause inside the seeds and terminate their diapause, finish their post-embryonic growth and emerge from the seeds when the seeds are sown (Medjdoub-Bensaad et al., 2007). However, survival and emergence after sowing varies depending on soil moisture and is particularly low in the UK (B. Ward, personal communication, April 2016). In contrast, survival is high in Mediterranean regions (e.g., Kabylia, Medjdoub-Bensaad et al., 2007). No data has been found on the survival rates of weevils overwintering in the seeds in Sweden and emergence after sowing.

Field colonization, mobility and sexual maturity

Males' sexual maturation is triggered by an increased proportion of light in the photoperiod, such that they are sexually mature when they colonize the field when the crop reaches leaf development. More specifically, a day length of 16h is required for the weevils to terminate their reproductive diapause, which is observed in early May in Southern and Central Sweden (Malmö: from May 10; Stockholm: from May 2). An optimal day length of 18h is found to induce diapause termination, which is observed in Stockholm at the end of May (Tran and Huignard, 1992).

Females are still in reproductive diapause when they colonize the field once crops reach flowering stage and day temperature reach 20°C. They become sexually mature in a few days, as a result of both an increased duration of photophase and the ingestion of faba bean pollen and nectar (Tran and Huignard 1992).

Adults are extremely mobile during the day, and find refuge in resting sites in flowers and young leaves at night and early morning (Huignard et al., 1991). They migrate from crop to crop following flower availability (Huignard et al., 1991). Field density can vary, but numbers are around 20 adults/100 plants at the beginning of the colonization and 150 adults/100 plants at population peak when pressure is high (in France, B. Frerot, personal communication, June 2016).

Fields near overwintering sites such as woody and herbaceous environment, and storage facilities, present increased risk of *B. rufimanus* colonization, particularly in areas with high infestation the precedent year. In addition, pest pressure is generally higher near field edges (B. Frerot, personal communication, June 2016).

Mating and oviposition

Once males and females are both sexually mature, mating is spread over a few weeks. Insects are active when temperature reaches 20°C; temperatures above 25°C are very favorable to their activity in the field whereas colder temperatures below 15°C and wet weather limit insect mobility (B. Ward, personal communication, April 2016; observed in the UK in 2007 & 2008, Lole, 2009).

Once fertilized, females *B. rufimanus* lay eggs on developing pods of faba beans. There is no data on eggs laid on other plant species. Rain, wind and temperatures below 20°C put on hold the oviposition process. Eggs are laid predominantly on the lowest parts of the plant (Biddle and Ward, 1998; Bruce et al., 2011). Eggs are small (< 2mm diameter), white-yellowish (Fig. 2, Arvalis and UNIP, 2014). A maximum of ten eggs per pod is observed. Females lay between 50 and 100 eggs. Egg mortality might be increased by rain (Arvalis and UNIP, 2014).

Larval development and adult emergence

After about 10 days (1-3 weeks depending on temperatures, no data on degree-days has been found), larvae hatch and bore directly throughout the pod walls and develop within the seed. Two to three larvae can bore in one seed (Hoffmann, 1945, p. 43). Larvae are thus protected from biological and chemical control. Larval development lasts two to three months. Before entering its pupal stage, the larva cuts a circular cap (Fig. 2). After around ten days of pupal stage, the adult emerges from the seeds.

Because mating and oviposition are spread over a few weeks, adults can emerge before or after harvest. In France, most adults emerge when day temperatures are still high (20-25°C) (Arvalis, 2016). Because temperatures drop early in autumn in Sweden, larvae and pupae might instead enter into diapause and therefore overwinter in the seeds in the storage facility. I found no information regarding the timing of *B. rufimanus* emergence in autumn in Sweden.

Effect on faba beans

Although *B. rufimanus* does not directly affect faba bean yield, it alters the aesthetic quality of the seeds as well as its germinative properties and ensuing yield is therefore an issue for human consumption and seed markets. A maximum 3% damage threshold is set for seeds targeting market for human consumption. Damaged seeds (seeds from which adults have emerged) might have lower germination rates with 13% reduced germination observed in the lab, but no difference observed in the field (Epperlein, 1992). Yield from infested beans are lower (-45% to -70%) than for healthy ones (Epperlein, 1992). In addition, damaged seeds have increased susceptibility to rust and root diseases (Epperlein, 1992).

Additionally, the presence of living insects on seeds are an issue for the export market as no living insects are allowed for export. The presence of weevils in the seeds after harvest thereby decreases faba bean commercial value.

Management options

The larval stages of *B. rufimanus* occur inside the seeds (Fig. 3), and are therefore protected from any control measures, including chemical control. *Bruchus rufimanus* is most vulnerable at the adult stage. Most control measures have therefore targeted adults either at colonization stage in the field or at emergence in storage facilities. Control measures have been focused on direct control with insecticides, but restrictions and removal from market due to environmental concerns have increased the need for alternative measures. Only one insecticide (Biscaya) is currently authorized for use in the field against *B. rufimanus* in Sweden. Research projects to develop pest management are ongoing in the UK and in France in collaboration with growers.

Monitoring

Because of their larval development inside the seeds which are protected by the pods, most inventorying methods are based on population of *B. rufimanus* adult in the field or at emergence.

At field colonization: estimation of adult population density

- *Adult counts*

Adult population can be estimated by counting all adults *B. rufimanus* on 100 plants once they start colonizing the field until 5-10 days after the end of flowering (BBCH 51-77). Tapping the flowering stems into a tray fasten the process.

- *Semiochemical-baited trapping system*

The development semiochemical attractants trapping systems for both monitoring and pest control has received particular interest in ongoing research on the weevil. A monitoring system based on semiochemical-baited trapping system (attraction traps) based on floral sents (see below) is being used in the UK (B. Ward, personal communication, April 2016). Other traps are being developed in France (Leppik et al., 2014; B. Frerot, personal communication, June 2016, Fig. 4).

At seed formation stage: estimation of egg density

Egg counts on young developing pods (>2cm) can be done during the oviposition period, although eggs are small (<1mm length), green-yellowish, therefore difficult to observe (Fig. 2). In addition, population estimate are difficult to obtain as egg laying is spread over time until 5-10 days after the end of flowering (BBCH 77).

After harvest: infested and damaged seeds count

- *Direct method*

Seed quality can be observed manually at harvest (100 to 200 seeds/field) and characterized according to pest damage:

- Seeds can be healthy, with no trace of damage
- Seeds can contain developing larvae
- Seeds can show trace of emerged *B. rufimanus* adult (a hole in the seed)

The count is time consuming with around 20min/100 seeds (B. Raffiot, personal communication, June 2016).

- *Indirect methods*

Alternative methods have been used to evaluate infestation of seeds:

- Differences in seed density due to the presence of the developing larva or of the hole left by the emerged adult could be used to faster quantify damaged seeds
- Tomography analysis of seeds has been developed for PeaMUST project (B. Raffiot, personal communication, June 2016). Eight samples of 100 seeds can be processed in 10 minutes, after which images should be digitally analyzed. This counting system is not yet available commercially (B. Raffiot, personal communication, June 2016).
- The emergence of *B. rufimanus* can be induced via a solution of NaOCl and chinosol in 7 days at 30°C (Girsch et al., 1999). The solution induces the end of larval and pupal diapause so that most insects emerge after treatment and an overall infestation rate can be assessed. This method has been commonly used in Austria (Girsch et al., 1999).

Control methods

Direct methods

Direct measures can be taken in the field, to prevent the oviposition and direct damages on the seeds, or in storage facilities, to reduce the adult population and therefore the pressure for the next year. Chemical control in the field represents the main measure to control the weevils in conventional seed production in

Europe and particularly in Sweden (Claes-Göran Henriksson, personal communication, June 2016), whereas in California, field treatments are not recommended by the board of agriculture, and the control instead focuses on treatments in storage facilities (Rachel Long, personal communication, June 2016).

Direct control in the field

- *Chemical control*

In Europe, pyrethroids and neonicotinoids are commercialized against *B. rufimanus* adults. Because of the faba bean crop biology and its attraction to pollinators at flowering stage which in Sweden occurs from mid-June to mid-July, restrictions on pesticides uses have been introduced. It is advised to spray in absence of pollinators in the early morning and evening (Arvalis, 2016). Previously commonly used insecticides, mainly pyrethroids, have been removed from the Swedish market due to environmental concerns.
Only one insecticide is currently authorized against *B. rufimanus* in field bean fields in Sweden (Jordbruksverket, 2016b): Biscaya OD 240 (Tiakloprid, nenicotinoid, Bayer, Germany) during flowering (BBCH 61-77). I found very little information on the efficacy of Biscaya on the weevils. One field trial (L13-6060, Jordbruksverket) showed no effect in the 2011 growing season when the pest pressure was very low. I found no additional data on field trials with Biscaya OD 240, nor any specific trials assessing the risks associated with its use on pollinators (Lundin et al., 2015). This highlights a need to estimate pest pressure before treatments, for example using semiochemical baited traps as in the UK (B. Ward, personal communication, April 2016). I found no publication on the efficacy of pyrethroids or neonicotinoids and particularly Biscaya on *B. rufimanus.* Seidenglanz et al. (2011) showed ovicidal effects of pyrethroids and neonicotinoids on a related species, the pea weevil *B. pisorum* L. with particularly 50% efficacy for Tiacloprid.

In addition, due to *B. rufimanus'* biology, a temperature threshold combined with crop development stage have been used to increase the success of chemical treatments (Ward and Smart, 2011). Insecticides should be applied once crop stage reaches young pod development (> 2cm) and once day temperature has reached 20°C for two consecutive days (Ward and Smart, 2011).This has been confirmed by insecticide trials in Sweden which showed the effect of crop development time on the success of insecticide application (Karate®, Syngenta, Switzerland): a 19% decrease in insect damage was observed when treatment was done after flowering whereas no effect was found when treatment was done before flowering (in Sweden, trial L13-6060, Jordbruksverket, 2011). Treatments performed when climatic conditions and field development are not met reduce the effect of insecticides, and might explain the small, or absence of, effect observed in some cases show small or no effect on final damage after harvest, e.g., trial with Deltamethrin (pyrethroid), (Biddle and Ward, 1998).

To target resting adults and therefore to best protect the flowering part of the plant, high water volume (150-200 l/ha) is advised (Arvalis, 2016). However, no information on the impact on efficiency of increased water volume on *B. rufimanus* nor on non-target insects such as pollinators was found.

Adult *B. rufimanus* activity increases with temperature, so that treatment efficiency might increase when maximum day temperatures are over 20°C during four consecutive days after treatment (Arvalis, 2016). Depending on prospected market and economic damage threshold, a second treatment can be recommended seven days after the first treatment if weather conditions are met, although there was no difference observed for one versus two treatments during the 2010 cropping season in Sweden (trial L13-6060, insecticide: Karate®, Jordbruksverket, 2011).

The end of blooming indicates the end of adult activity in the field. This stage is therefore a threshold marking the end of insecticide application which should stop no later than five days after last blooming according to Arvalis (2016).

Forecasting systems have been developed to optimize insecticide applications based on:

- Temperature and crop stage (Bruchi-LIS, Arvalis, France and BruchidCast, Syngenta, UK).
- Infestation pressure of *B. rufimanus*, estimated with a semiochemical-baited monitoring trapping system (B. Ward, personal communication, April 2016, see below).

In addition, a similar management in a same growing region is recommended due to the high mobility of adults *B. rufimanus* (Arvalis, 2016), although no data on the impact of concerted spraying on *B. rufimanus* population and damages has been found.

According to data from Scandinavian seeds (2015), a small reduction (8% ± 3%, mean ± SD across varieties) in yield was found on untreated fields compared with fields treated with insecticides against *B. rufimanus* in Sweden (average yield across varieties: treated: 5728 kg/ha; untreated: 5306 kg/ha).

- *Attractive traps based on semiochemical attractants*

The field colonization by *B. rufimanus* is induced by faba bean volatiles (Bruce et al., 2011; Leppik et al., 2014): sexually mature males are attracted by faba bean flowers volatiles, and females are highly attracted by faba bean flower volatiles and the presence of males (Leppik et al., 2014). Semiochemicals have been synthesized from faba bean flower (Bruce et al., 2011; optimized by Leppik et al., 2014), targeting males and females *B. rufimanus* when they colonize the field, and from faba bean pods (B. Frerot, personal communication, June 2016), targeting fertilized females before oviposition, and for which a patent has been recently obtained. Another attractant is being investigated to target the emerging adults from seeds before they reach their overwintering sites (B. Frerot, personal communication, June 2016).

A trapping system using semiochemicals synthesized from faba bean pods is in development in France and is currently being tested (Fig. 4) in the field to control *B. rufimanus* (B. Frerot, personal communication, June 2016). Its potential use for biological control of *B. rufimanus* will be assessed this summer and further development and commercialization is expected in 2017 (B. Frerot, personal communication, June 2016).

Figure 4. Semiochemical-based trapping system currently being developed by INRA, France. Catches of B. rufimanus *in glue traps with synthetic attractant based on floral scents are 60 times more numerous than the control during blooming period (Leppik et al., 2014). Picture: E. Leppik.*

- *Entomopathogenic fungi*

Recent work has highlighted the potential of entomopathogenic fungi (particularly *Beauveria bassiana*) to control *B. rufimanus* (Sabbour and E-Abd-El-Aziz, 2007). So far, no entomopathogenic fungi is currently commercially available for bruchid control. The use of *B. bassiana* is currently tested against *B. rufimanus* in a 'lure and kill' system in the UK (project IUK 101910, B. Ward, personal communication, April 2016).

- *Botanical oils*

Recent work has highlighted the repellent and insecticidal properties of botanical oils against *B. rufimanus* and their potential to be used in pest management (Liu et al., 2006; Sabbour and E-Abd-El-Aziz, 2007). Plant treated with nigella and mustard oils were less attractive to *B. rufimanus,* which laid fewer eggs than untreated plants (up to 90% reduction depending to oil concentration, Sabbour and E-Abd-El-Aziz, 2007). The repellent properties of nigella and mustard oils were long lasting (up to 7 days, Sabbour and E-Abd-El-Aziz, 2007). A mixture of Japanese mugwort (*Artemisia princeps* P.) and camphor trees (*Cinnamomum camphora* (L.) J. Presl.) showed repellent and insecticidal properties against *B. rufimanus* adults (Liu et al., 2006). No toxicity of the oil mixture to seed germination was observed on wheat (Liu et al., 2006). No data on commercial utilization of botanical oils has been found. Field trials testing the insecticidal properties of botanical oils are currently undertaken in France by *Terres Inovia*.

Direct control in storage facilities

Although the measures taken in storage facilities do not decrease the proportion of damaged seeds, they limit the densities of emerging insects and therefore the pressure for the coming year. Such measures will be especially efficient in storage as most *B. rufimanus* have then not yet emerged and are still developing in the seeds. Early harvest could therefore be recommended for best control measures in storage facilities (Terres Inovia, 2016).

- *Warm water or air*

Exposition of seeds to warm air (50 to 70°C, depending duration) kills *B. rufimanus* developing into the seeds at the same time it lowers water content. However, warmth can decrease germination rates of the seeds, which would be problematic for the seed market. No data was found on temperature treatment threshold for faba bean germination success. The visual aspect and the protein content of the seeds can also be degraded by too high temperatures. More research is needed to assess the potential of this method for the different markets for seed, animal feed and human consumption (Sylvie Dauguet, personal communication, June 2016).

- *Fumigation and insecticide use*

Fumigants can be used against *B. rufimanus* in tightly sealed storage facilities. This method is particularly used in California (Godfrey and Long, 2014) and in Australia (Warrick, 2011).

Phosphine (also referred to as hydrogen phosphide) is used as fumigant against *B. rufimanus* although other gases can be used. Phosphine is highly toxic to all forms of animal life (FAO) although larvae and adults life stages of insects are more sensitive to pupae and eggs. A 10 day exposure is generally recommended for complete mortality, but its toxicity declines as temperatures fall to 5°C and is not recommended for use below 5°C (FAO). Fumigation with phosphine has no effect on grain germinative properties (FAO; Upadhyay and Ahmad, 2011) although yields might be affected when seeds are subjected to repeated fumigation as observed in Maize (Joubert and Du Toit, 1969).

Its toxicity to animals and humans is critical so that the use of fumigation is under strict regulations for the permissible workspace atmospheric concentrations and sealing restrictions, which increases the costs related to storage fumigation (Banks, 1994). In addition, there has been rising concerns on the development of insect resistance to phosphine (Highley, 1994; Mills, 2000), particularly in Australia (Warrick, 2011). No data on its allowance and potential use is Sweden was found.

In France, K-Obiol® ULV 6 (Pyrethroid, Bayer, Germany) can be used to control emerging *B. rufimanus* in storage facilities. The insecticide targets emerging adults by contact and ingestion. It leaves detectable insecticide residues on the seeds. This insecticide is only approved for use against infestation in grain stocks in Sweden according to the Swedish Chemical Agency (June 2016).

- *Trapping of newly emerged insects*

By sealing the storage facilities, newly emerged adults from seeds could be prevented from escaping to their overwintering sites to decrease the pest pressure at the next season. *B. rufimanus* could then be trapped and later killed, e.g., by fire.

In addition, a storage extended over two years enables all developing *B. rufimanus* to emerge before sowing and therefore avoids emergence in the field from contaminated seeds. The logistic needed for a 2 year-storage is however difficult to implement as space for storage is limited.

- *Sorting and elimination of damaged seeds*

To ensure seed quality is met (damages below the 3% threshold for human consumption, no live insects remaining), an optic sorter is being used by a cooperative in France to sort healthy and damaged seeds (Pierrick Basset, personal communication, May 2016).

Preventive control methods

The pressure from *B. rufimanus* seems unaffected by management practices and cultivar although little data is available. Because *B. rufimanus* biology is highly linked to crop development and climatic conditions, pest damage and pressure the next year can vary according to sowing and harvesting date (Fig. 3). In addition, sanitation can help decreasing the source of *B. rufimanus* in production areas (Godfrey and Long, 2014).

Sowing date

Crops with delayed sowing of more than 10 days showed less damages from *B. rufimanus* (Szafirowska, 2013; B. Ward, personal communication, April 2016) although a decrease in yields can be observed between early and late sowing for some cultivars (Szafirowska, 2013). However, because of the high mobility of *B. rufimanus* adults, fields sown later are getting colonized from field sown earlier after flowering stage (B. Raffiot, personal communication, June 2016). In addition, early sowing is favored in Sweden due to the short cropping season.

Cultivar

There was no resistance or tolerance to *B. rufimanus* adults observed in field trials between varieties (in the UK, Biddle and Ward, 1998) and particularly with/without tannins and with/without vicines (in France, B. Raffiot, personal communication, June 2016). Similarly, there was no difference in varietal susceptibility to larval damage of the seeds (Biddle and Ward, 1998). However, differences in susceptibility was observed between cultivars in Poland where up to 70% decrease in damage between cultivars was observed (Kaniuczak, 2004; Szafirowska, 2013). None of the cultivars studied in the UK and Poland are grown in Sweden (seed library Scandinavian Seeds, accessed June 2016).

Research is currently undertaken to breed tolerant cultivars (project PeaMUST, work package 2, 2012-2019, INRA, France). A wild relative to faba bean has been found to be tolerant to *B. rufimanus* (B. Raffiot, personal communication, June 2016). The project is ongoing to identify tolerant genotypes, integrate these genotypes in breeding programs, and to identify the genes involved in the tolerance mechanisms. The first field trials with the evaluation of *B. melanarius* tolerance are planned for 2016 and 2017 (B. Raffiot, personal communication, June 2016).

Sanitation
A careful elimination of the potential sources of *B. rufimanus* in the production areas can help reducing the field infestation. The UC Pest Management Guidelines cite the "broken sacks of field beans left over from planting, seed beans left in planting hoppers, cull beans used in animal feed programs in a production area, small collections of beans remaining on or in a harvester following harvest, and small piles of beans remaining in or around the field after harvest or in a warehouse area" (Godfrey and Long, 2014).

Other methods
No impact of intercropping (wheat, Gallo et al. 2012; mustard, B. Raffiot, personal communication, June 2016) has been found in term of damages from *B. rufimanus.* However, damages from *B. rufimanus* might vary according to plant density (Stoddard et al., 2010) although no affirmative information could be found on this aspect. Finally, no data is available on the effect of fertilization on damages by *B. rufimanus.* Marzo et al. (1997) studied a related species, *B. pisorum* and found no differences in damages under different P and S fertilization regimes.

Biological control

Parasitoids have been found to parasitize *B. rufimanus* eggs: *Chremylus rubiginosus* and *Triaspis thoracicus* (family: Braconidae), and *Dinarmus acutus* (family: Pteromalidae). Their larvae develop into *B. rufimanus* larvae and adults emerge from the seed, leaving a small emergence hole in the seed (smaller than for *B. rufimanus*). All three species are found in Sweden (Svensk taxonomisk database, 2016) but no data has been found on their potential for *B. rufimanus* control in Sweden, and in particularly whether parasitoids can colonize the field at the time of the oviposition of *B. rufimanus*. Unpublished trials in France have excluded the use of parasitoids in biological control strategies (B. Raffiot, personal communication, June 2016).

Generalist predators on faba bean leaves such as spiders might feed on *B. rufimanus* eggs and contribute to their biological control although no data was found on their potential impact on the population size or growth.

Conclusions and future directions

Bruchus rufimanus has a relatively simple life cycle with only one generation per year, with all its larval stages occurring within the developing seeds, inside the pods. *Bruchus rufimanus* is already a threat in Sweden and risks are increasing with the increasing area devoted to faba bean production observed in the past years in Sweden and neighboring countries. In view of the little information available on the status of *B. rufimanus* in Sweden and in Northern Europe, future investigations could clarify the risks for faba bean production and help identify the potential measures both in term of field management and direct control that could be recommended in Sweden. More particularly, there is a call for data on the origin of emerging adults and their potential to overwinter in natural habitat given climatic conditions in the different regions growing faba beans. In addition, there is a need for a better understanding of the timing of *B. rufinamus* emergence according to faba bean harvest in the different growing regions in Sweden. This would allow control measures to be focused either in storage facilities or in the field at adult colonization (Fig. 3).

Research on the potential methods to control the emerging adults in the storage facilities (and particularly temperature treatments) could reduce the pest pressure in Sweden if faba beans are harvested before most adult population emerge. The development of semiochemical baited trapping system is also a promising approach. If the field trials currently run in France were successful, it could be interesting to test the approach in Sweden during the next field season. Last but not least, information on natural enemies (parasitoid and generalist predators) of *B. rufimanus* and particularly at the egg stage and their potential to reduce damages would enable to draw recommendation measures to support biological control of the pest.

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